SOIL STABILIZATION

INITIAL LABORATORY AND FIELD TESTS OF QUICKLIME AS A SOIL-STABILIZING MATERIAL

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PREFACE

The investigation reported herein was conducted for the Office, Chief of Engineers, under the authority of Subproject 8-70-03-107, "Solidifying or Stabilizing Soils for Military Operations."

This report describes initial laboratory and field investigations of quicklime as a soil-stabilizing material conducted at the U. S. Army Engineer Waterways Experiment Station during the period October 1956 to June 1957.

Engineers of the Waterways Experiment Station actively connected with the study were Messrs. D. R. Freitag, G. R. Kozan, B. G. Schreiner, and J. E. Mitchell. The work was conducted under the general direction of Messrs. W. J. Turnbull and W. G. Shockley. This report was prepared by Mr. Kozan.

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SUMMARY

A need exists for a soil-stabilization material that will be suitable for use during military operations in which supporting vehicles are required to negotiate a wet, unstable area without excessive delay. Previous laboratory investigations using both a lean clay and a heavy clay had indicated quicklime to be particularly effective in stabilizing very wet soils.

This study was conducted to: (a) investigate the suitability of quicklime as a stabilizing material for very soft soils; (b) examine the validity of requirements proposed for this type of stabilizer; and (c) determine the suitability of conventional equipment for constructing a stabilized surface in a wet, soft soil. Laboratory tests were first conducted, primarily to examine effectiveness of quicklime as a stabilizing material but also to determine the amount of quicklime to use in stabilizing a field test section. A test section simulating an untrafficable subgrade was then prepared and treated with 8.0% quicklime based on dry soil weight. Traffic tests were made with an M-51 truck loaded to 10,000 lb.

The field investigation verified the ability of the chemical to react as indicated in laboratory tests. However, a condition of nonuniform strength and thickness of the stabilized surface layer resulted from extremely poor mixing of the soil and stabilizer. For this reason the test section failed to meet trafficability requirements, and the validity of the proposed requirements for this type stabilizer could not be evaluated.

It is recommended that investigation of quicklime as a stabilizer for very wet soils be continued concurrently with efforts directed toward development or improvement of mixing techniques, so that satisfactory evaluation of the material and of the proposed requirements for a stabilizer will be possible.

SOIL STABILIZATION

INITIAL LABORATORY AND FIELD TESTS OF QUICKLIME AS A SOIL-STABILIZING MATERIAL

PART I: INTRODUCTION

Purpose and Scope

1. This report summarizes the results of a limited laboratory investigation and field study of quicklime as a stabilizing material for wet, fine-grained soils. The work reported represents initial efforts to investigate a stabilizer for very wet and unstable soils which in their natural state are known to be untrafficable by military vehicles.

Background

2. In February 1956, tentative definitions of military road and airfield stabilization requirements were proposed in a memorandum to the Office, Chief of Engineers.* The military road stabilization requirements, as set forth in this memorandum, indicate that a major problem exists in what has been termed an assault or "trafficability" situation. This situation is encountered during a military operation when it is imperative that supporting vehicles negotiate immediately an area of extremely wet and unstable soil. For such a contingency, a stabilizing material is required that can be placed with a minimum of construction effort, and that will, within one hour after completion of construction, stabilize the soil sufficiently to support traffic of combat vehicles for a short period of time. In terms of wheel loads and traffic intensity, the stabilization afforded should permit a minimum of 50 passes by tanks with gross loads of 50 tons and trucks with wheel loads to 10,000 lb. Using these requirements (hereafter referred to as "category 1" stabilization requirements) as a guide, it was estimated that a satisfactory degree of stabilization would be

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* Memorandum by U. S. Army Engineer Waterways Experiment Station, to Office, Chief of Engineers, "Proposed Long-range Plan of Test for Soil Stabilization," dated February 1956.

achieved by increasing the strength of the top 12 to 18 in. of a weak soil to a minimum CBR of 4. This is equivalent to a cone index of about 120 or an unconfined compressive strength of about 25 psi.

3. After an extensive review of existing stabilizers, preliminary laboratory test programs were initiated by the Massachusetts Institute of Technology (under contract No. DA 22-079-eng-171) and the Waterways Experiment Station to investigate numerous materials and determine their potential as category 1 stabilizers. Of the materials examined, both hydrated lime and quicklime appeared to be highly effective, with quicklime imparting sufficient strength to a lean clay and a heavy clay to meet the laboratory requirements established for category 1 stabilization. On the basis of the laboratory findings, it was decided to examine the capability of quicklime under simulated field conditions.

Objectives

4. The primary objectives of this investigation were to:

a. Evaluate, by means of an actual traffic test, the ability of quicklime to stabilize a very wet, fine-grained soil known to be untrafficable by military vehicles in its natural state.

b. Investigate the validity of the requirements proposed for a category 1 stabilizing material.

c. Determine the suitability, and/or limitations, of conventional construction equipment for constructing a quicklime-stabilized surface in a wet, soft soil.

Test Program

5. The test program comprised a limited laboratory investigation, and the subsequent construction and traffic-testing of a field test section. The laboratory investigation consisted of preparing specimens containing various amounts of quicklime and determining their strength by unconfined compression and cone penetration tests, in accordance with established laboratory procedure. The field test section, 12 ft wide by 75 ft long, was designed to have a 12-in.-thick quicklime-treated surface constructed on a lean clay subgrade having a cone index of approximately

20 (equivalent to a CBR of less than 1). On the basis of the laboratory findings, the amount of quicklime to be mixed with the soil was specified as 8%, based on dry soil weight. The test lane was traffic-tested with a 5-ton truck, M-51, loaded to off-highway capacity (gross load of 31,800 lb), with tires inflated to 50-psi pressure. Cone index measurements, soil remolding indexes, and water content and density data were obtained during construction of the subgrade and surface, and before and after traffic-testing, for correlation with traffic performance data.

PART II: CHARACTERISTICS OF MATERIALS USED

Stabilizing Material

6. A commercially produced, pulverized, high-calcium quicklime containing 92% by weight calcium oxide was used as the stabilizing material in these tests. Although a complete chemical analysis was not made of this specific material, analyses of typical commercial high-calcium quicklimes indicate the following average composition:*

Component	% (Range)
Calcium oxide (CaO)	93.25-98.00
Magnesium oxide (MgO)	0.30-2.50
Silica (SiO_2)	0.20-1.50
Ferric oxide (Fe_2O_3)	0.10-0.40
Aluminum oxide (Al_2O_3)	0.10-0.50
Water (H_2O)	0.10-0.90
Carbon dioxide (CO_2)	0.40-1.50

A typical distribution of particle sizes consists of 100% passing a U. S. Standard sieve No. 20, and 85-90% passing a No. 100 sieve. The quicklime was supplied by the manufacturer in multiwalled paper sacks, each containing 50 lb.

7. Quicklime, in contrast to hydrated lime, is an anhydrous product and is highly reactive with water, generating considerable heat in the hydration process. Therefore, quicklime is considered somewhat hazardous to work with, since it may cause burns on coming in contact with perspiring skin. To minimize this hazard during the field tests, suitable protective clothing was furnished to each individual handling the quicklime and also to the operators of the construction equipment.

Soil

8. An inorganic lean clay soil native to the WES grounds was used in

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* Reported in Chemical Lime Facts, Bulletin 214, Washington, D. C., National Lime Association (1951).

the laboratory investigations and in the construction of the field test lane. The soil is loessial and is classified as CL by the Unified Soil Classification System. It has an average liquid limit of 38 and plasticity index of 16. The maximum dry density of the material resulting from the standard Proctor compaction effort was 108 lb per cu ft at an optimum water content of 17%. Grain-size data indicated 97% of the soil to be finer than 0.074 mm (No. 200 sieve) and approximately 25% to be finer than 0.005 mm.

PART III: LABORATORY INVESTIGATION

Test Criteria

9. Before the laboratory tests were begun, it was necessary to establish suitable test criteria and procedures that would be indicative of the effectiveness of a given stabilizer for category 1 stabilization. A basic premise in the establishment of the requirements for this type of stabilization was that it is not reasonable to attempt to stabilize a soil having a water content higher than the field maximum. The field maximum water content is defined as the highest recurring water content that can be attained by soils that are not inundated or located below the water table. For any particular soil area this value is fairly specific and will recur frequently during the wet season. It is, however, dependent on the soil type and the soil's physical characteristics in situ. For the lean clay soil used in this investigation, the probable field maximum natural water content was estimated from existing data to range from 30 to 33%. At this water content, a laboratory-prepared specimen would be expected to have a cone index between 10 and 20.

10. Based on current trafficability studies,* a soil with a rating cone index (product of measured cone index and remolding index) of 120 has sufficient bearing strength to allow at least 50 passes of all 4-wheel-drive, self-propelled wheeled vehicles and tracked vehicles used by the military. Since considerable effort is required to prepare compacted specimens of sufficient size for laboratory cone index measurements, a criterion based on an unconfined compressive strength test was established for initial screening of potential category 1 stabilizers. For the soil used in this investigation, an approximate relationship of cone index and unconfined compressive strength was developed from available data on the untreated soil. Based on this relationship, it was estimated that an unconfined compressive strength of 25 psi was equivalent to a cone index of

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* U. S. Army Engineer Waterways Experiment Station, CE, Trafficability of Soils - A Summary of Trafficability Studies through 1955, Technical Memorandum No. 3-240, 14th Supplement (Vicksburg, Mississippi, December 1956).

120. A stabilizer found capable of developing compressive strengths of about 25 psi in a sample moist-cured for one hour would be examined further by means of a cone penetrometer test on larger laboratory-compacted specimens. The stabilizer would be considered suitable for field testing if it increased the cone index of the soil, after one hour of moist-curing, to the minimum 120 believed necessary for category 1 stabilization.

Tests and Results

Unconfined compression

11. For the laboratory tests to determine the unconfined compressive strength of quicklime-treated soil specimens, the test specimens were prepared in the following manner: A sufficient quantity of the soil described in paragraph 8 to complete the full test series was air-dried, pulverized to remove large lumps, and thoroughly mixed to achieve uniformity. Water was added to the soil to achieve a desired initial water content of 33%. Then the soil was sealed in airtight containers and allowed to equilibrate for at least 24 hr. After this period, treated samples of the soil were prepared by adding quicklime in amounts of 1, 3, 5, 8, and 10% of the dry weight of the soil and thoroughly blending the mixture by hand. Duplicate specimens from each of the five mixtures, and from the untreated soil for comparison, were then placed in Harvard miniature compaction molds, 1-5/16 in. in diameter by 2.82 in. long. The soil was placed in the molds in five layers and each layer was compacted, using the Harvard miniature compaction apparatus, with 10 blows of a 20-lb spring tamper. The molds were then sealed to prevent water loss by the samples, and placed in a humid room to cure for 1 hr. On completion of the curing period, the specimens were extruded from the molds and tested to failure by unconfined compression. The results of the strength tests, including initial and final water content and density data, are given in table 1.

12. It should be noted that the water contents are recorded on the basis of dry weight of total solids rather than on a dry soil weight basis. This was done because the total quantity of solids contributed by the chemical in the stabilized soil mass was not equal to the amount of quicklime added. This is evident from the following expression of the chemical

reaction that takes place when pure calcium oxide reacts with water to form calcium hydroxide or hydrated lime:

$$CaO + H_2O \rightarrow Ca\,(OH)_2$$

From the molecular weights of the materials used in the reaction, it can be shown that, assuming complete reaction, a 10% treatment of quicklime will result in the formation of 13.2% hydrated lime with the removal of 3.2% of available water from a soil mass (percentages based on dry soil weight). Based on the stoichiometric expression, a relationship can be developed showing the effect of quicklime on the water content of a soil-water-chemical system, as follows:

$$W_{ts} = \frac{W_s - 0.32\,(Q)}{100 + 1.32\,(Q)} \times 100$$

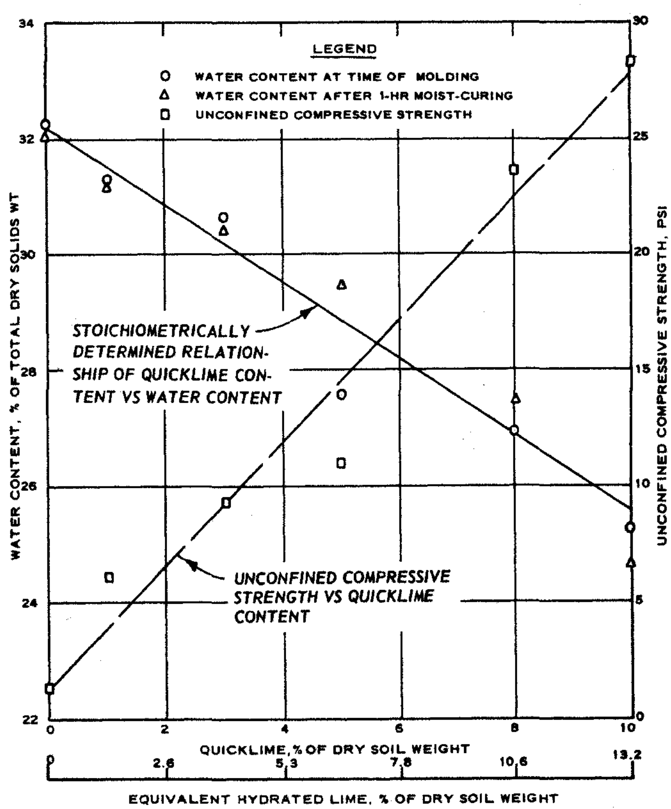

Fig. 1. Effect of quicklime on water content and unconfined compressive strength of Vicksburg loess (initial water content equals 32.2%)

where:

W_{ts} = water content after hydration, in per cent, based on total dry solids weight

W_s = initial water content of soil, in per cent, based on dry soil weight

Q = quantity of quicklime added, in per cent, based on dry soil weight

The effect of quicklime on water content, as determined by the above expression, is shown in fig. 1. The initial water content of the soil was assumed constant at 32.2% (average of untreated-soil water contents in table 1). Fig. 1 also includes plots of the water contents of the treated soil both at the time of molding and after one-hour moist-curing (from table 1). The data conform well with the stoichiometrically determined relationship, indicating that the quicklime is quickly converted to hydrated lime upon contact with the wet soil.

13. Also shown in fig. 1 is the relationship between quicklime content and unconfined compression test results. It is evident that the strength of the soil increases significantly as the percentage of quicklime used is increased, and that the relationship is apparently rectilinear in the range of 0 to 10% quicklime for the particular initial soil water content used. Part of the increase in strength may be attributed to the decrease in water content of the treated soil as a result of the hydration of the quicklime. For example, the addition of 10% quicklime to soil at 32% water content resulted in a decrease of water content of the treated mass to 25%. In general, untreated soil at this water content has an unconfined compressive strength of about 8 psi. However, since the strength of the treated soil (10%) was 28 psi, it is evident that the greater portion of the strength increase is the result of a stabilizing reaction of the hydrated lime with the soil, rather than the result of drying.

Cone penetration

14. A cone penetrometer test was next conducted on laboratory-prepared specimens to determine the ability of quicklime-treated soil to meet cone index requirements. The soil was prepared at 33.0% water content in the same manner as the unconfined compression test samples. Quicklime, in the quantity of 8.0% by dry soil weight, was added to the soil and thoroughly mixed in by hand. The admixture was compacted in a 10-in.-diam by 7-in.-high CBR mold with 25 tamps applied on each of three layers with an asphalt compaction hammer (4-in.-diam foot, 10-lb hammer, 18-in. drop). A control specimen of untreated soil was prepared also, but vibrating as well as tamping was employed to achieve densification because of the extremely soft condition of the soil. The prepared specimens were sealed in the molds and allowed to cure for a period of one hour in the humid room. Cone index measurements were made at the surface and at depths of 1, 2, 3, 4, and 5 in. in the molded specimen, using a trafficability penetrometer with an end area of 1/2 sq in. Five sets of readings were made at representative locations on the specimen. Table 2 summarizes cone index data.

15. It is apparent from the data that a significant increase in penetrometer resistance was achieved by the addition of 8.0% of quicklime. After one-hour moist-curing, cone index values had increased from an average of about 6 in the untreated soil to well over 300 in the treated soil. It should be noted that at the initial water content of 33%, representing the upper limit of the estimated range of field maximum water content for this soil, the measured cone index of the untreated soil was somewhat lower than anticipated. The effect of reducing the initial water content to a lesser value, however, would be to increase the strength of the treated soil even more than indicated in table 2. It is evident from the data that an addition of 8.0% quicklime is more than adequate to meet the laboratory strength requirements established for category 1 stabilization.

Atterberg limits

16. Another interesting characteristic of quicklime is its ability to alter the relative consistency of a soil at any given water content. The degree to which the consistency is altered depends primarily upon the soil type, and is reflected in any soil by a change in the Atterberg limits. The effect of various percentages of quicklime on the Atterberg limits of the lean clay (loess) used in this investigation is shown in fig. 2. The limits tests were conducted on the quicklime-treated samples after a curing period of 24 hours under humid-room conditions. It can be seen that both the plastic and liquid limits increased somewhat as a result of the action of the quicklime, but the net effect was a negligible change in the plasticity index. Also, it is apparent that maximum values for the limits occurred at low percentages of quicklime (1 to 3% by dry soil weight), and that these limits remained fairly constant when greater percentages of lime were used. The increases in the limits probably resulted from the aggregating influence of the quicklime, and are significant in that they reflect changes in the engineering

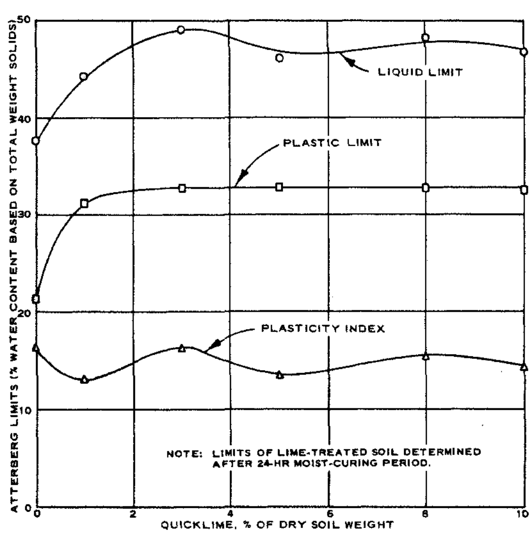

Fig. 2. Effect of quicklime on Atterberg limits of Vicksburg loess

properties of the soil, as well as its response to mixing and compacting at a given water content. In most cases, an increase in the limits of a soil requiring category 1 stabilization, particularly in the plastic limit, with little or no increase in the resulting plasticity index, is desirable and beneficial.

PART IV: FIELD INVESTIGATION

Construction of Test Section

Location and layout

17. The test lane was constructed under shelter so that the soil water content would be affected as little as possible by weather conditions. The treated surface portion of the lane was 12 ft wide by 75 ft long. Shoulders, consisting of untreated compacted soil, were provided on each side of the lane, and turnaround areas for construction and trafficking equipment were constructed at both ends of the test lane. The layout of the test lane area is shown in fig. 3.

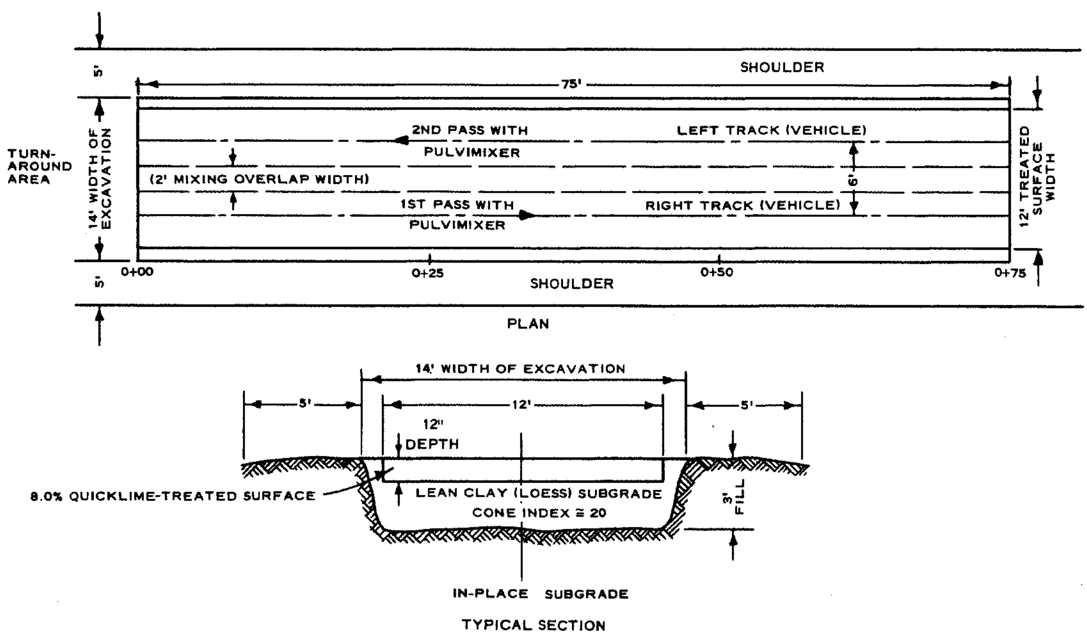

Fig. 3. Layout and cross section of quicklime test lane

Subgrade

18. The subgrade consisted of the lean clay soil described in paragraph 8 placed at a water content that would result in a cone index of approximately 20. To achieve this, the existing soil was excavated to a depth of 36 in. below finished surface grade elevation. The width of the excavation was approximately 12 ft measured at the bottom, and approximately 14 ft across the top. A view of the excavation before the subgrade fill material was placed is shown in fig. 4. Soil, which previously had

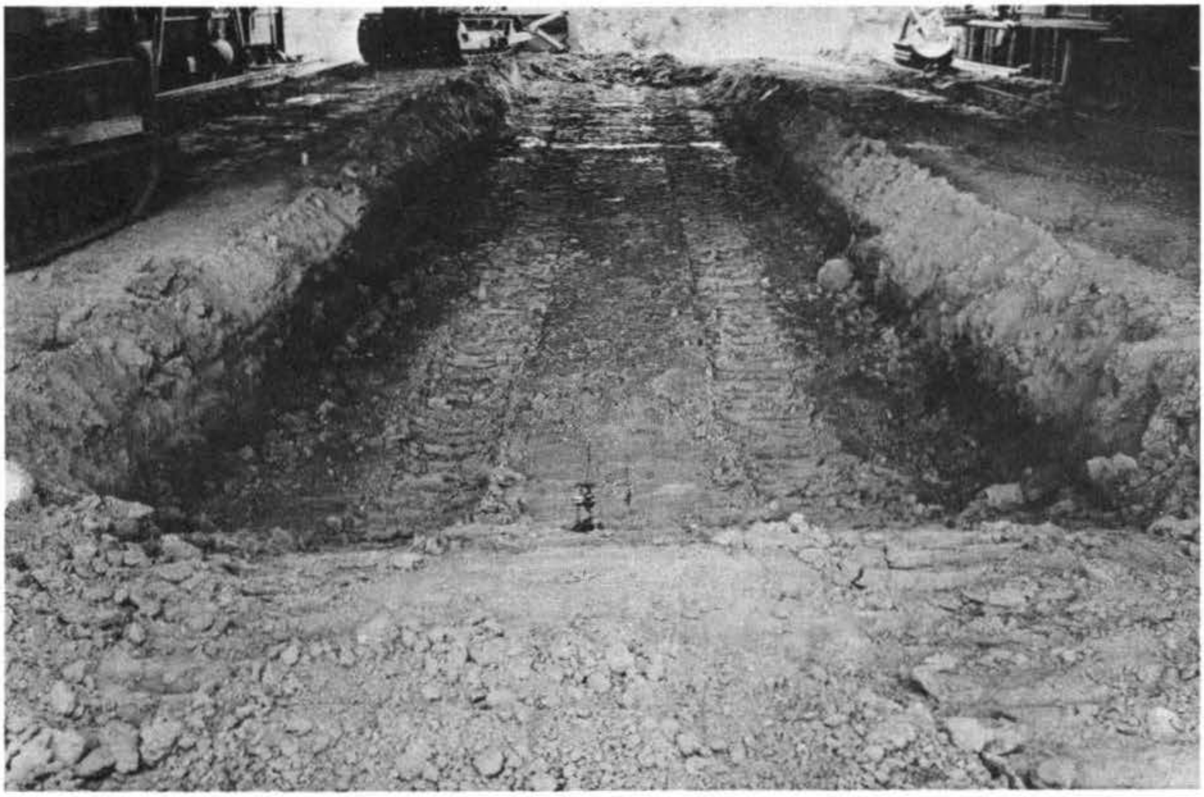

Fig. 4. Excavation prior to placement of subgrade fill material

been processed to a uniform water content of 14%, was placed in the excavation and spread to a uniform thickness by hand as illustrated in fig. 5. The soil was placed in lift thicknesses slightly greater than 3 in. which, when wetted to the desired water content, resulted in 3-in.-thick consolidated layers. Thus, 12 lifts were required to obtain a 36-in. depth of subgrade. After each lift was placed, a water-distributing truck was used to apply sufficient water uniformly on the lift to achieve the desired subgrade strength (fig. 6). To allow time for the water to be absorbed uniformly, only two lifts were placed each day. The completed subgrade is shown in fig. 7.

19. Cone and remolding indexes, water content, and density tests were conducted for control during construction of the subgrade. Table 3 presents the subgrade data taken immediately prior to treatment with quicklime. The cone index values shown were obtained at 5-ft intervals along the anticipated left and right wheel paths of the vehicle, or 3 ft on each side of the center line of the lane. These data show an increase in

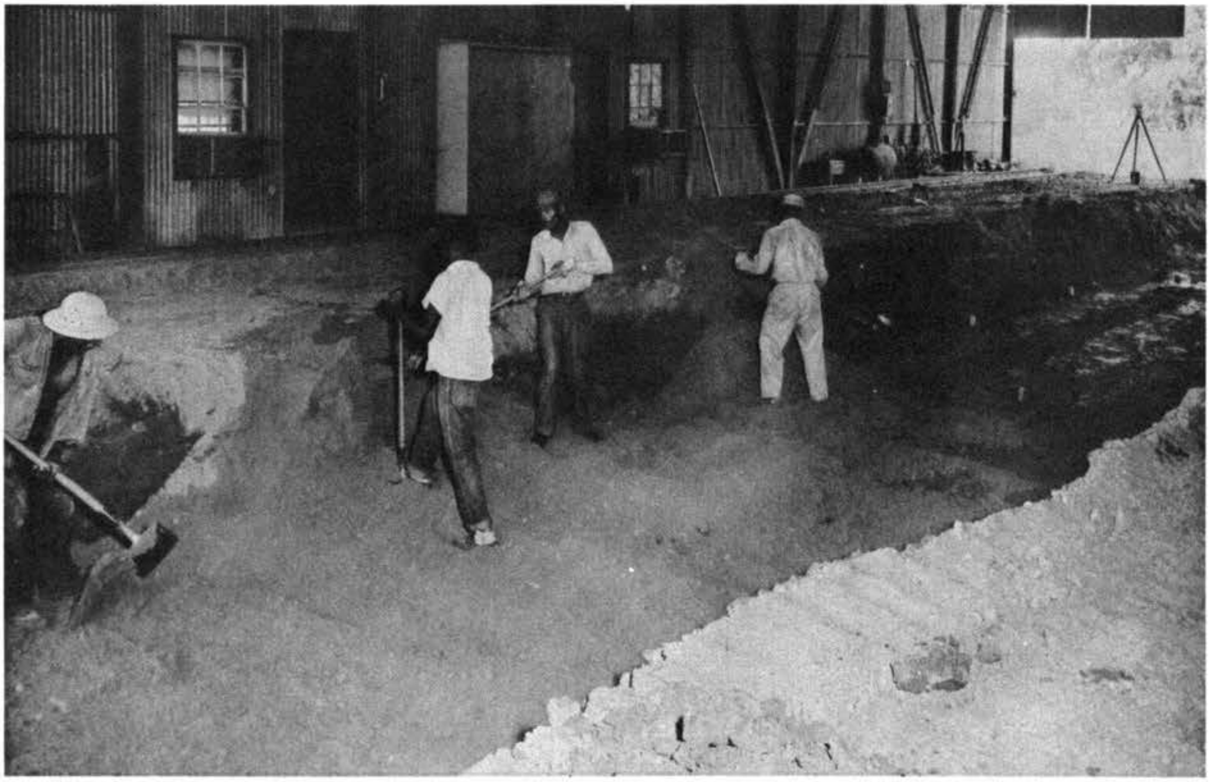

Fig. 5. Hand-spreading of first lift to uniform thickness at bottom of excavation

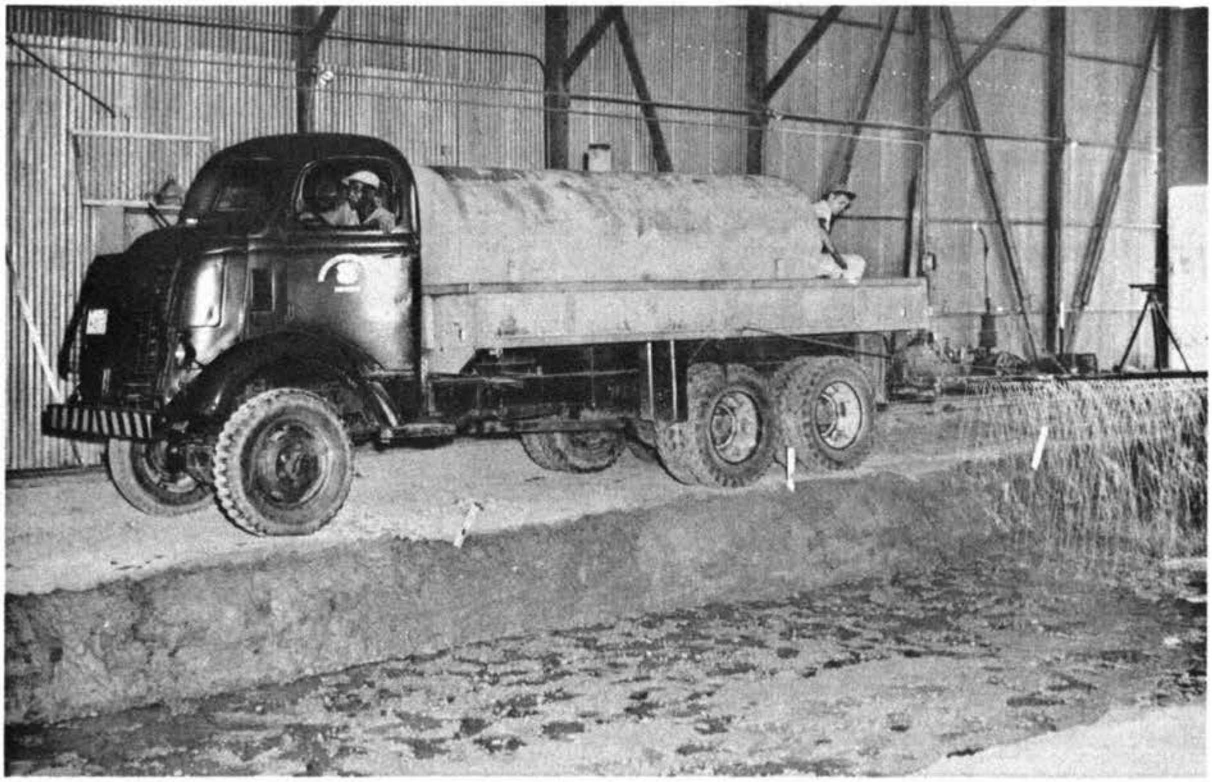

Fig. 6. Application of water on lift to achieve desired subgrade strength

Fig. 7. Completed subgrade immediately prior to spreading of quicklime

penetration resistance at each increment of depth. This strength increase occurred in spite of the fact that the subgrade was constructed uniformly with respect to water content and density, as is also shown by the data in table 3. A plot of the cone index values obtained during various stages of construction vs thickness of overburden is shown in fig. 8, and a

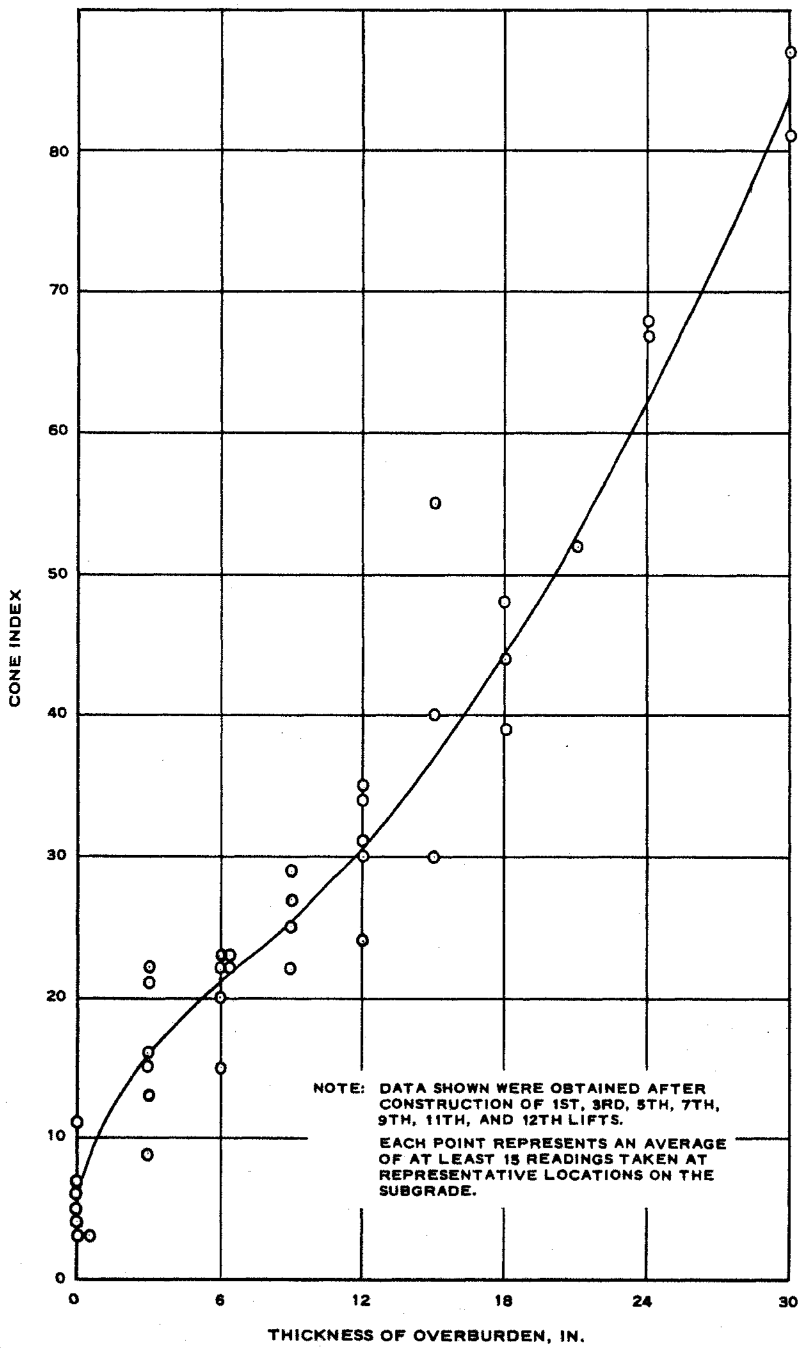

Fig. 8. Relationship of cone index vs thickness of overburden (loess subgrade fill)

general relationship is indicated. The trend of the data is typical of a soil strength profile determined by means of a penetration-type test. However, it should be mentioned that only a very small portion of the increase in penetration resistance with depth can be explained on the basis of overburden pressures. It is possible that some thixotropic hardening took place during the construction period, although no effects of this nature have been noted with this soil in laboratory testing programs. In addition, it is conceivable that certain factors peculiar to penetrometer measurements may have had some influence on the results obtained.

20. From the data shown in table 3, the rating cone index of the prepared subgrade, which represents the criterion of trafficability, can be determined. By definition, the critical layer of a soil is the one most pertinent in establishing a relationship between soil strength and vehicle performance. For wheeled vehicles with gross weights to 50,000 lb, the critical layer in a soil with a normal strength profile (cone index increases with depth) is the layer between the 6- to 12-in. depth.* Since the effect of remolding, or change in strength that may occur under traffic, is negligible as indicated by the remolding index of 0.98, the rating cone index of the prepared subgrade is determined to be 26.

21. In addition to the cone indexes measured along the wheel paths, readings were taken at varying distances from the left edge of the lane at sta 0+20 and 0+50 to obtain cross-section representation of subgrade strength. The results are tabulated in the upper part of table 3, along with averages for each depth increment at both stations. The values compare favorably with those in table 1 at comparable depths, thus indicating uniformity of initial subgrade conditions in all areas of the test section.

Surface Treatment

Placement of quicklime

22. After completion of the specified subgrade tests, the lane was ready for application of the quicklime (fig. 7). Based on the results of the laboratory tests, it was concluded that an 8.0% (by dry soil weight)

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* Waterways Experiment Station, op. cit.

treatment of quicklime should be provided. Although the laboratory cone index tests showed strengths considerably higher than the desired 120 cone index with this percentage of admixture (table 2), experience has shown that strengths achieved in the field may be 50%, or less, of that obtainable in the laboratory because of differences in mixing efficiency. Therefore, it was anticipated that an 8.0% treatment would, in all probability, provide cone indexes not far in excess of the desired minimum of 120. Sufficient quicklime was used to achieve the desired treatment for the top 12 in. of the test lane. Bags of quicklime were stacked at equal intervals along the lane adjacent to the test strip; the quicklime was then dumped on the surface of the lane and spread by hand to a uniform thickness over the entire area to be treated. Since the untreated soil was too soft to support a man's weight, it was necessary to span the lane with plank bridges to enable the workmen to apply the lime. These operations, and the appearance of the test lane immediately before mixing, are shown in figs. 9 and 10.

Fig. 9. Placing and spreading quicklime on test strip

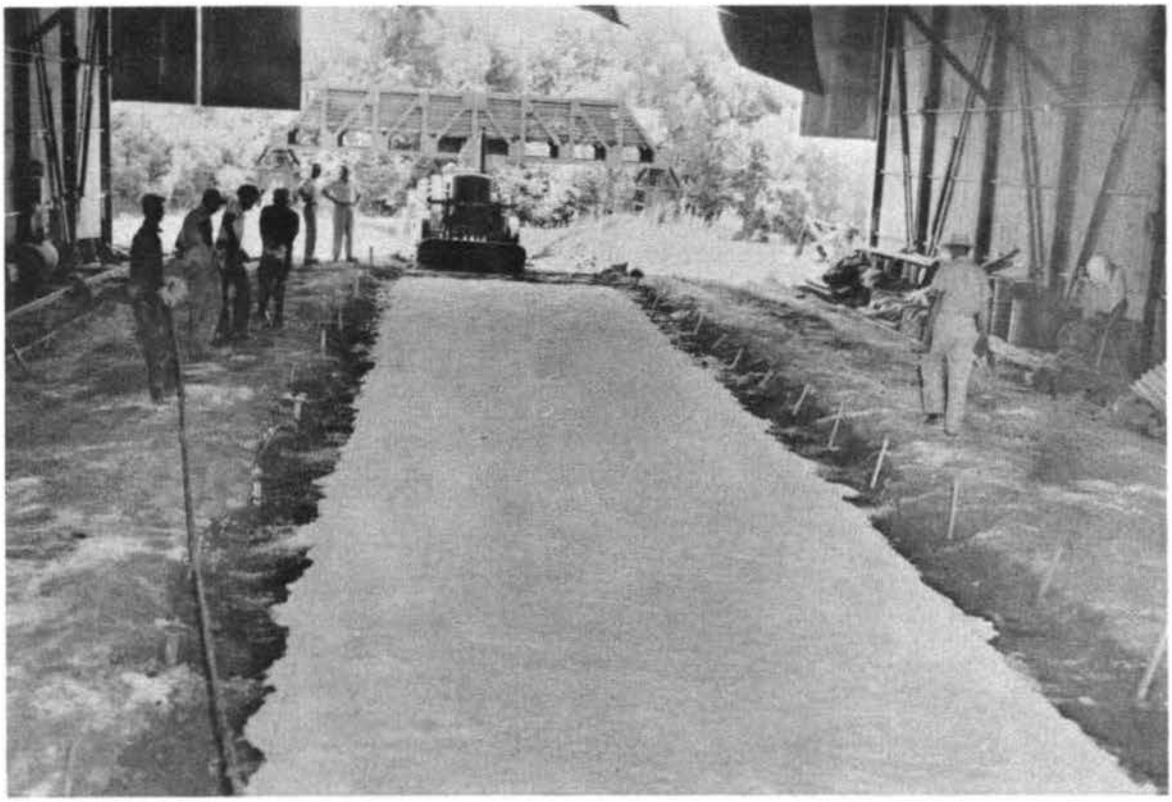


Fig. 10. Appearance of test lane prior to mixing

Mixing operations

23. A standard self-propelled Seaman pulvimixer was employed to mix the lime with the soil. However, because the soil would not support the pulvimixer, it was necessary to devise a method for pulling the mixer over the lane without its sinking into the subgrade. This was accomplished by placing the tractor portion on a "mud" sled, with the mixer unit protruding beyond the rear of the sled as shown in fig. 11. The rotors were adjusted to achieve a 12-in. mixing depth. Mobility was provided by attaching a heavy cable to the front of the sled and pulling the unit over the test lane by means of a power winch attached to a D-7 tractor. A preliminary test run of this rig was conducted during construction of the subgrade and was reasonably successful, though the process was slow and time consuming. Since the width of the test lane was 12 ft, two passes in opposite directions were necessary to obtain one complete mixing coverage with the 7-ft-wide rotor unit.

24. Two complete coverages were made with the sled-mounted pulvimixer during which the subgrade successfully supported the unit with no

Fig. 11. Pulvimixer and sled arrangement devised to provide support for the mixer on the low-strength test lane

observed deformation. However, several other difficulties were evident. The quicklime piled up in front of the sled to some extent and formed a windrow of material along the sides. This material was shoveled back, to be mixed on the next pass. It was also observed that the depth of mixing achieved was considerably less than the 12 in. desired because the rotors tended to ride on the surface rather than cut into the soil. This caused a considerable amount of quicklime to be thrown into the air, creating difficulty and discomfort for the operator in the sheltered area. After the two complete mixing coverages had been made, the pulvimixer was dismounted from the sled and an attempt was made to drive it over the lane under its own power. It was hoped that the initial mixing had been sufficient to provide a surface capable of supporting the pulvimixer. Unfortunately, this was not the case, and the pulvimixer bogged down after traveling about 20 ft. The mixer was winched through the remaining distance, creating ruts 12 to 18 in. deep, and no further mixing was attempted. Approximately one hour was consumed in the mixing operation.

25. Compaction. Immediately after mixing, an attempt was made to compact the test lane by "walking-down" with a D-7 tractor. Although the tractor made two successful passes under its own power, considerable shoving was observed and ruts in excess of 12 in. deep were formed. To smooth out the ruts and complete compaction, a standard M-29C cargo carrier (weasel) was operated over the lane for a total of 25 passes (about three complete coverages). No difficulties were encountered with this vehicle, although large deflections of the surface were observed under the moving load. The appearance of the test lane at completion of construction is shown in fig. 12. The presence of a considerable amount of unmixed

Fig. 12. Completed test lane. Note unmixed quicklime on and adjacent to lane

quicklime along the sides of the test lane and also on the surface is evident in the photograph. The total elapsed time from the start of the mixing operation to completion of compaction was two hours.

Evaluation Tests

26. Subgrade evaluation tests were initiated approximately 40

minutes after compaction of the treated test section was completed. The tests were similar to those conducted on the subgrade before the quicklime was applied. A summary of the after-treatment subgrade data measured in the anticipated wheel paths of the test vehicle is shown in table 4. As indicated by the cone index data, the effectiveness of the quicklime treatment varied in different areas of the test lane. To aid in the evaluation, average strengths are shown in table 4 for 25-ft sections of the lane, from sta 0+00 to 0+25, 0+25 to 0+50, and 0+50 to 0+75 (hereafter called "analysis areas" of the lane). However, no attempt was made to average the cone indexes of the right and left traffic paths, since significant differences were observed between these areas of the lane. Similarly, the nonuniformity of water content and density in the surface layer after the addition of quicklime is apparent from the data shown in table 4. Inadequate mixing is considered the major factor responsible for all observed lack of uniformity.

27. Cone index readings also were made in the subgrade across the lane at sta 0+20 and 0+50. These results are shown in the lower portion of table 5, and can be compared with the cone indexes immediately prior to treatment which are given in the upper part of that table. The results after treatment were not averaged since differences in strength are evident between the left and right sides of the lane, the latter side appearing to be better stabilized at both stations.

28. An unsuccessful attempt was made to obtain cylindrical samples of the treated surface for unconfined compression testing. The friable condition of the treated soil, as well as its low density, made sampling difficult, and it was virtually impossible to extrude a whole sample from the sampling cylinders without considerable fracture or deformation.

Traffic Tests

29. Traffic by a standard 5-ton dump truck, M-51 (fig. 13), loaded to an off-highway capacity of 10,000 lb, was attempted approximately one hour after construction of the test lane was completed. The test vehicle has a dual-tandem rear wheel configuration, a rear wheel spacing of 6 ft, and a rear axle spacing of 54 in. The tires were size 11.00x20, 12 ply,

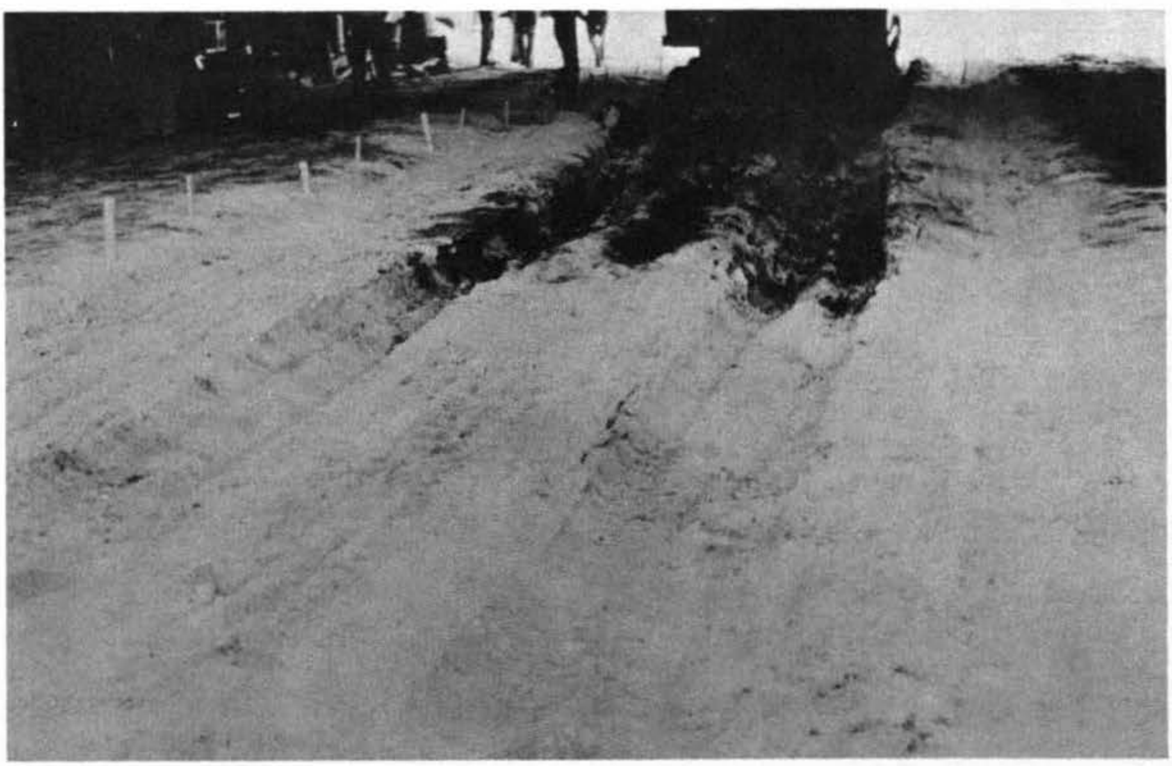
and were inflated to a pressure of 50 psi. The gross load of the vehicle was 31,800 lb, of which 23,000 lb were distributed to the rear wheels.

30. An initial attempt by the vehicle to enter the test lane at sta 0+00 proved unsuccessful, as illustrated in fig. 14. Immediately upon entering the area of weak subgrade, the front wheels broke through the thin, stabilized crust and settled into the soft soil beneath. The vehicle

Fig. 13. M-51 test vehicle; 31,800-lb gross load, 50-psi tire pressure

Fig. 14. Failure of test section at sta 0+00 during entry of vehicle

a. Front of vehicle at sta 0+10



b. View from sta 0+75 of rear of truck. Note differences in depth of ruts throughout length of test lane

Fig. 15. Immobilization of test vehicle after first pass

was backed out without difficulty, and an attempt was made to enter the lane from the other end at sta 0+75. This was accomplished successfully and the vehicle was allowed to continue through the test lane. Shallow ruts ranging from 2 to 6 in. in depth were observed from sta 0+75 to 0+60 during the first pass. From sta 0+55 to 0+10, the axle of the vehicle was dragging and ruts 7 to 12 in. deep were formed. The truck was able to complete the initial pass without immobilization but could not pull out of the test lane at sta 0+00. An unsuccessful attempt was made to back the truck out in the path created by the first pass, and it was necessary to winch the vehicle out with the D-7 tractor. Immobilization of the truck after completion of the first pass is shown in figs. 15a and 15b.

31. Since immobilization did not occur on the first pass in the section of the test lane from sta 0+75 to 0+55, and since the ruts were relatively shallow, it was decided to continue traffic on this area. An additional 16 passes of the truck (for a total of 17 passes) were made before the vehicle's undercarriage began to drag and immobilization was considered imminent. The depth of ruts at the termination of the test ranged from 9 to 13 in. A profile of the test lane, indicating the depth of rutting in both the right and left track made by the vehicle, is shown in fig. 16.

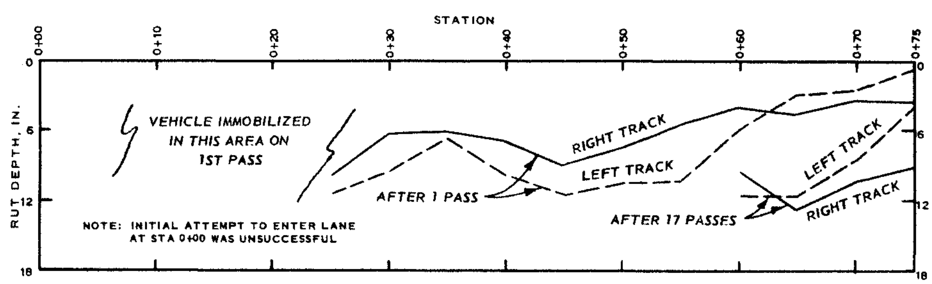


Fig. 16. Rut-depth profile after traffic with M-51

PART V: ANALYSIS AND DISCUSSION OF FIELD TEST RESULTS

Effect of Treatment on Bearing Strength

32. Based on cone penetration test results, the strength of the test lane subgrade before treatment with quicklime was reasonably uniform and increased with depth. The average rating cone index value of the untreated subgrade was 26, which is insufficient to support any military vehicle except the cargo carriers, T46E1 (otter) and M29C (weasel). After treatment with quicklime, significant changes occurred in the characteristics of the wet soil, as evidenced by differences in the water content, degree of aggregation, and bearing strength of the treated and untreated materials. Unfortunately, the treatment was not uniform because of poor mixing, and isolated masses of unstabilized soil were evident throughout the test area. To illustrate graphically the differences in the strength of the test section before and after treatment with quicklime, cone index profiles to a depth of 30 in. are plotted in fig. 17. These profiles show the cone

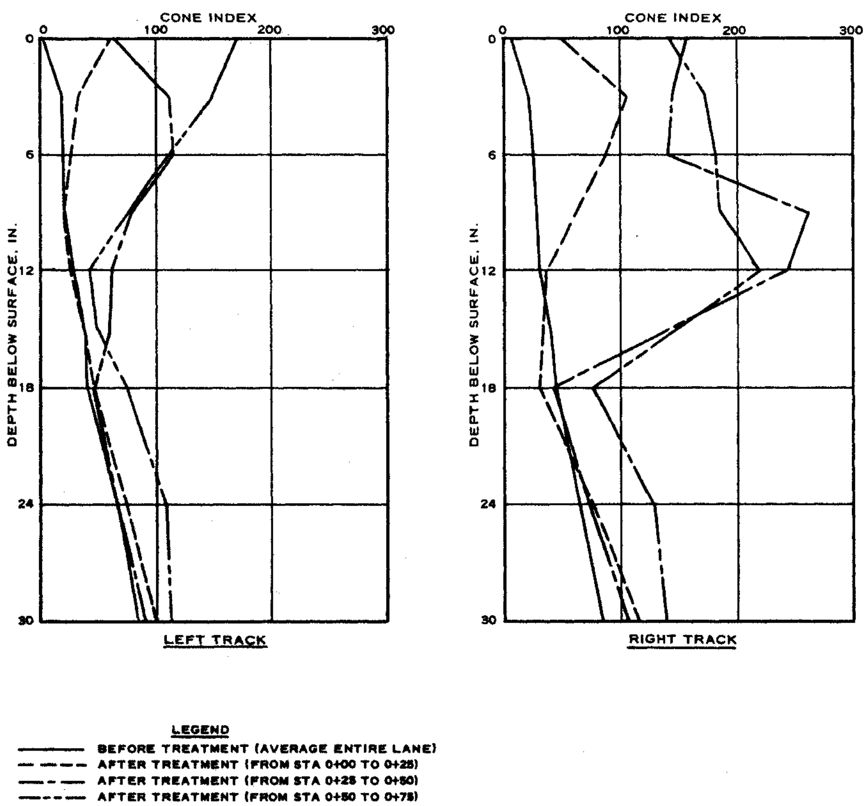


Fig. 17. Profiles of cone index at 0- to 30-in. depth before and after treatment with quicklime

indexes at various depths for both the right and left traffic paths. It is to be noted that averages of the entire test lane were used to plot profiles of the untreated subgrade, while the profiles after treatment are representative of the three analysis areas of the test lane as indicated.

33. The effectiveness of quicklime stabilization in the test lane is indicated by fig. 17. Comparison of the cone index profiles taken in the right and left track of the test lane shows that stabilization was significantly more effective on the right side. On the left side of the lane, the only area to achieve the desired minimum cone index of 120 was that from sta 0+50 to 0+75, and this was accomplished only to a depth of about 6 in. The strength profiles for the right side of the lane indicate, however, that sufficient stabilization was achieved to increase the cone index to well over 120 to a depth of at least 12 in. from sta 0+25 to 0+75. From sta 0+00 to 0+25, practically no stabilization occurred in any portion of the test lane. This was further demonstrated by the inability of the test vehicle to enter the lane at sta 0+00.

Effect of Traffic on Treated Surface

34. For any vehicle, a minimum soil cone index necessary to complete 50 passes may be determined by using a method developed for trafficability analysis.* The empirical formula used to compute the cone index required, or vehicle cone index, is intended to afford a conservative value. For the M-51 truck used in this traffic test, a vehicle cone index of 66 was determined. Thus, if the rating cone index of an area is 66 or greater, it is highly probably that the vehicle can complete 50 passes in that area without being immobilized. It was stated previously (paragraph 20) that the determination of the rating cone index for an area is dependent on both the configuration of the soil strength profile and the type of vehicle expected to traverse the area. Since the untreated subgrade had a normal strength profile, the rating cone index was based on the strength of the layer between the 6- to 12-in. depths. The treated-subgrade strength profiles in fig. 17 show that in all three analysis areas, with

* Waterways Experiment Station, op. cit.

the exception of the left-track section from sta 0+00 to 0+25, the measured cone indexes in the 12- to 18-in. layer were less than those in the 6- to 12-in., or normally critical layer. Experience in trafficability has shown that if this situation exists, the strength most indicative of trafficability performance is the lowest rating cone index occurring in either the 6- to 12-in. or the 12- to 18-in. layer. To assist in evaluating the quicklime-treated test lane for trafficability of the M-51 truck, the measured cone indexes and corresponding rating cone indexes for each of the analysis areas of the lane are tabulated below. Since the effect of remolding on strength was insignificant, the determination of the rating cone indexes from the measured values did not require use of a correction factor.

	Measured Cone Index					
	Sta 0+00 to 0+25		Sta 0+25 to 0+50		Sta 0+50 to 0+75	
Depth	Left	Right	Left	Right	Left	Right
Surface	63	48	65	156	173	140
6 in.	29	88	113	141	111	181
12 in.	28	36	63	243	43	218
18 in.	48	29	50	42	76	77
24 in.	75	77	70	75	108	128
6- to 12-in. layer	28	62	88	192	77	199
12- to 18-in. layer	38	32	56	142	59	147
Rating cone index	28	32	56	142	59	147

35. From the rating cone index of the test lane from sta 0+00 to 0+25, it is evident that the M-51, with a vehicle cone index of 66, could not be expected to negotiate the area even for a single pass. Examination of the rating cone indexes of the other two analysis areas indicates little difference to be anticipated in the behavior under traffic between the two. For both areas the rating cone index in the left vehicle track is somewhat less than the vehicle cone index of 66, which suggests immobilization before 50 passes. However, the rating cone index in the right track is more than double that of the vehicle cone index. This indicates that considerably more than 50 passes could be made without immobilization if this rating were representative of the entire test area. Thus, it might be expected that: (a) the test vehicle would be immobilized before 50 passes as a result of the weaker left side of the lane; (b) the number of passes before immobilization in the areas from sta 0+25 to 0+50 and from sta 0+50

to 0+75 would be approximately the same; and (c) a difference in total displacement or rut depth would be evident between the right and left tracks.

36. In general, the actual behavior of the lane under traffic by the test vehicle corresponds to that anticipated from analysis of the rating cone index data. In no area of the test lane was the vehicle able to complete the 50 passes necessary to meet trafficability requirements. In the area from sta 0+00 to 0+25, immobilization occurred immediately, as would be expected. Somewhat contrary to anticipated behavior, however, was the fact that the vehicle was able to complete only one pass before creating excessive ruts in the area from sta 0+25 to 0+60, while 17 passes were made in the last 15-ft section of the lane (from sta 0+60 to 0+75). Undoubtedly, the extreme nonuniformity of strength was the major factor responsible for the differences in behavior observed between these two areas. It is possible, for example, that narrow lenses of stabilized soil resulted from the filling in of the ruts created during the attempts to mix and compact the soil. If these lenses occurred beneath a wheel path, the measurements made there would not reflect the influence of the weaker soil immediately adjacent and would therefore lead to overoptimistic estimates of performance. The cross-section strength data at sta 0+50 (shown in table 5) indicate that this may have been the case in the area where only one pass was made.

37. As can be seen from the rut-depth profiles plotted in fig. 16 (page 25), the left-track ruts were deeper than the right-track ruts by from 1 to 6 in., except in the area from sta 0+65 to 0+75. The marked variation in depth of rutting that occurred throughout the lane, even within the selected analysis areas, can, in general, be related to the cone indexes measured within the top 18 in. When the average cone index for the top 18 in. at each station plotted in fig. 18 is compared with the one-pass rut-depth profile shown in fig. 16, this relationship is readily apparent. It can be seen, for example, that the depth of ruts observed in both tracks between sta 0+30 and 0+40 is less than in the area where immobilization occurred, or in the area from sta 0+40 to 0+55. The plot of cone indexes shows that high values were obtained between sta 0+30 and 0+40 compared to those in adjacent areas, particularly in the left track. Similar relationships with rut depth exist for the average 0- to 12-in.-layer cone index and for the rating cone index, but they are not as well defined.

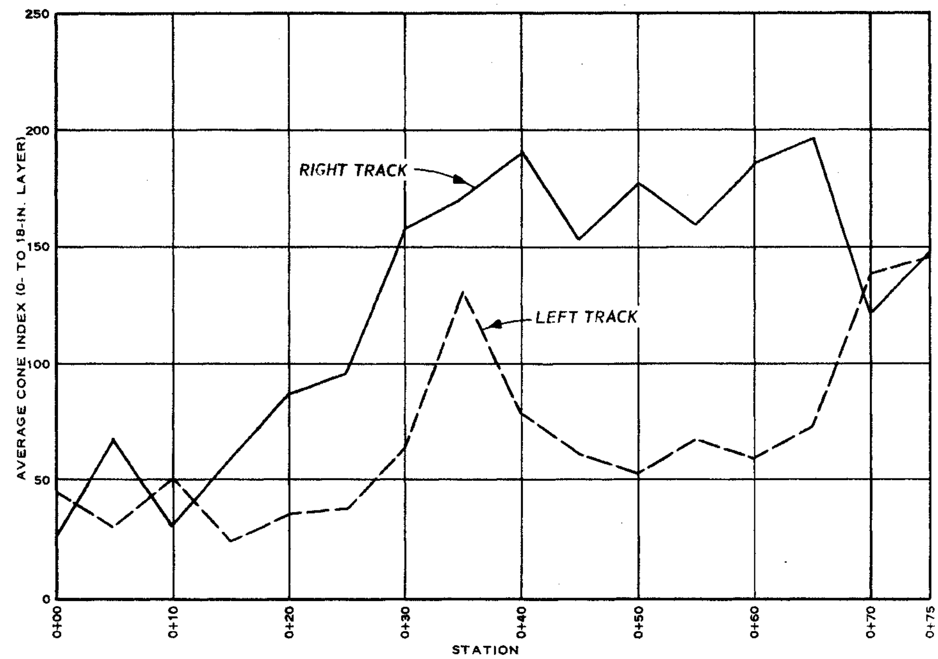


Fig. 18. Average cone index strength of 0- to 18-in. layer in wheel paths after quicklime treatment

Evaluation of Mixing Techniques

38. As described previously, considerable difficulty was encountered during the mixing operations. Evidence of the poor mixing achieved was indicated by the nonuniformity in strength, final water content, and compacted density of the treated layer throughout the test section. Samples of treated soil for chemical determination of lime content were taken to depths of 16 in. at sta 0+20 and 0+50. The chemical analysis consisted of a titration test to determine the quantity of available calcium oxide. This method of analysis is limited in that: (1) the quantity of quicklime that may not have converted to calcium hydroxide (hydrated lime) cannot be ascertained, and (2) the portion of the lime that may have combined chemically with the soil is not indicated. The first limitation does not invalidate the determination of either the total quicklime added to the soil mass or the gross distribution, and is not considered serious. To obtain an estimate of the quantity involved in the second limitation, control samples, at specified percentages of quicklime, were prepared and analyzed. The results indicated that, on the average, 2.3% of calcium oxide by dry

soil weight was not determinable by the titration test. The titration test data on all samples removed from the test lane were corrected by this amount to afford results which, although perhaps not truly precise, are believed to be indicative of the actual quantities and distribution of quicklime achieved.

39. The average corrected quicklime content of all the samples removed from the test lane was 4.4% by weight of dry soil, with values ranging from 2.5 to 7%. From samples taken in the vicinity of sta 0+20, the lime content averaged 3.6%, while an average of 5.3% was determined from samples at sta 0+50. Thus, in support of observations based on both strength and traffic performance data, better stabilization was achieved at sta 0+50 than at sta 0+20. However, the poor gross distribution of quicklime in the test section, reflected by a high coefficient of variation of 26% (ratio of standard deviation to arithmetical mean) for the samples analyzed, was believed to be the major factor responsible for the nonuniformity observed in the other test data.

40. For the purpose of this investigation, the standard pulvimixer was inadequate, resulting in unsatisfactory incorporation of the quicklime into the soil. The use of the mud sled to aid in load distribution and prevent rutting was only partially successful, as it tended to pile up the quicklime in front and along the sides. The control of the depth of mixing by the pulvimixer when mounted on the sled was poor, because the blades of the rotor had a tendency to ride on the surface of the soil. This resulted in significant variations in thickness of the treated layer, with subsequent effect on the behavior of the test lane under traffic. In addition, visual observations of small isolated masses of lime in samples removed from beneath the surface revealed that intimate contact of the quicklime with the soil particles was not achieved.

41. Similar mixing problems may be anticipated wherever a "trafficability" or category 1 situation exists. Since existing field mixing equipment is apparently unsatisfactory, a need for development of more suitable equipment and/or mixing techniques is indicated. It is possible that, with a more efficient blade configuration, the rotary blade principle can be utilized. On the other hand, it may be necessary to devise whole new concepts and principles of mixing in order to achieve the desired

results. A means of applying the stabilizer directly to the mixing point would probably improve mixing efficiency, as well as reduce stabilizer losses due to displacement by equipment or by the wind. In any event, equipment capable of operating in extremely soft soil areas is a requisite; the mobility of such equipment in other respects need not be high. The experience with this test lane seems to indicate a need for a tracked mixer having a soft ground capability similar to the weasel, or alternatively, a weasel-like prime mover towing the mixer mounted on a sled arrangement. However, it is possible that the critical problem of mobility could be alleviated by an arrangement in which the mixing unit would precede, or be mounted forward of, the power unit so that the driving wheels or tracks would travel on the treated soil.

Evaluation of Category 1 Stabilizer Requirements

42. One of the objectives of this investigation was to examine the validity of the requirements proposed for a category 1 stabilizing material. Unfortunately, the uniformity of the treated test section was such that a definitive analysis of the requirements on the basis of the observed traffic behavior could not be made. The measured cone indexes in the upper 12 in. of the subgrade after treatment ranged from 28 to 243, while the thickness of actual stabilized surface achieved varied from 1 in. to 12 in. Although the trafficability requirement of 50 passes with an M-51 truck loaded to 10,000 lb was not met in any area of the test section, the behavior of the lane corresponded generally to that which would be anticipated from the rating cone indexes. From the vehicle performance in the better stabilized areas, it is questionable that the trafficability requirement could have been satisfied even if uniform stabilization had been achieved to a depth of 12 in. This is consistent with trafficability observations that have indicated that the 12- to 18-in. layer is the governing critical layer if its rating cone index is lower than that of the normally critical 6- to 12-in. layer. Thus, the implication is that the proposed depth of stabilization of 12 in. is insufficient to meet the requirements for a category 1 situation. This statement is made with reservations, however, since the traffic behavior may have been influenced

more by nonuniformity in strength of the treated layer than by a deficiency in thickness. Any increase in the proposed depth requirement will, of course, necessitate the development of equipment capable of mixing to that depth, and this may present a serious problem.

Evaluation of Quicklime as a Category 1 Stabilizer

43. Quicklime has demonstrated an excellent potential as a stabilizing agent for the "trafficability" or category 1 situation. Its ability to transform a weak, wet soil mass into a firm and less plastic material within a short period of time renders it the most desirable material for category 1 stabilization examined to date. Based on laboratory tests and criteria, quicklime has surpassed the requirements established for a category 1 stabilizer. In the field it has demonstrated an ability to function chemically as indicated in the laboratory, but, as a result of poor mixing, it was unable to meet the trafficability requirements. Therefore, continued investigation of the use of quicklime for stabilization purposes is suggested, particularly with respect to developing improved techniques for incorporating the material into the problem soil.

44. The use of quicklime is acceptable from an economic standpoint. Stabilization of an area one mile long and 12 ft wide to a depth of 12 in. would require about 250 tons of quicklime, assuming an 8.0% treatment, at a cost of about $6000 for the material (exclusive of shipping and construction costs). The quantity of quicklime required probably can be reduced significantly if mixing can be improved. The relative abundance and availability of chemical lime in many places of the world make its use even more attractive. The chief disadvantages of quicklime are the hazards to personnel handling and storing the material, problems which may be minimized by means of proper safety precautions and the development of suitable containers.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

45. On the basis of this investigation, it is concluded that:

   a. Sufficient stabilization was achieved in a lean clay soil (Vicksburg loess) by addition of 8.0% quicklime (calcium oxide) to satisfy the laboratory requirements established for category 1 stabilization, with cone index values, after one-hour moist-curing, increasing from 6 for the untreated soil to over 300 for the treated soil.

   b. The addition of 8.0% quicklime to a lean clay subgrade having an initial rating cone index of 26 did not result in a uniformly stabilized surface because of poor mixing. The cone index of the treated soil varied from 28 to 243, and the thickness of the stabilized layer varied from 1 in. to 12 in. Although the stabilization achieved was not capable of meeting the requirements for trafficability of an M-51 truck loaded to 10,000 lb (vehicle cone index of 66), the quicklime demonstrated its ability to provide good stabilization in the isolated areas where intimate mixing was achieved.

   c. Data obtained from the traffic tests were inadequate to permit a definitive analysis of the effect on traffic behavior of a relatively strong stabilized surface of finite thickness, constructed on a weak subgrade.

   d. The completely inadequate mixing provided by the conventional equipment and techniques used to construct the quicklime-treated test section was believed largely responsible for the variations in cone index and thickness, and consequent failure of the test section to support the traffic placed upon it.

46. It is recommended that:

   a. Laboratory research with quicklime be continued in an effort to determine fully the capabilities of this material as a category 1 stabilizer, particularly with respect to the mechanisms that render it effective.

   b. Efforts be directed toward the development of new or improved equipment and techniques capable of adequately mixing a chemical with a wet, fine-grained soil.

   c. Additional field investigations using quicklime and/or hydrated lime be conducted, subsequent to improvement of mixing capability, for the purpose of more thoroughly evaluating these materials as category 1 stabilizers.

Table 1

Effect of Quicklime on Unconfined Compressive Strength of Vicksburg Loess

	As Molded		After 1-hr Moist-curing			
% Quicklime Dry Soil Weight	Water Content % Dry Solids Weight	Dry Density lb/cu ft	Water Content % Dry Solids Weight	Dry Density lb/cu ft	Strain at Maximum Stress %	Maximum Unconfined Compressive Strength psi
0.0	32.1	80.9	32.2	80.0	20.0	1.5
	32.4	81.0	31.9	87.1	20.0	1.3
1.0	31.6	86.3	31.3	88.2	10.5	6.4
	31.0	87.2	31.0	88.2	10.8	6.0
3.0	30.2	87.7	30.3	90.6	6.5	9.2
	31.1	87.4	30.6	88.4	7.9	9.4
5.0	27.3	90.3	29.5	89.8	6.5	10.7
	27.9	89.5	29.5	88.8	6.1	11.2
8.0	26.9	89.6	27.4	92.3	3.3	23.5
	27.0	90.5	27.7	91.3	4.3	23.9
10.0	25.5	86.3	24.8	88.9	2.0	28.4
	25.0	87.3	24.6	90.1	1.2	28.2

Table 2

Effect of Quicklime Treatment on Cone Index of Vicksburg Loess

Quicklime by Dry Soil Wt	Initial Water Content % Dry Soil Wt	Molded Dry Density lb/cu ft	Test Water Content after 1-hr Moist-curing % Dry Solids Wt	Cone Index at Indicated Depth of Penetration					
				Surface	1.0 in.	2.0 in.	3.0 in.	4.0 in.	5.0 in.
0.0	33.2	83.6	32.7	5.0	5.0	5.5	6.0	6.0	7.0
				4.5	5.5	6.0	6.0	6.0	7.0
				5.0	6.0	6.0	7.0	8.0	9.0
				4.5	5.0	5.5	6.0	6.5	8.0
				5.0	5.0	5.5	6.0	7.5	8.0
			Average	4.8	5.3	5.7	6.2	6.8	7.8
8.0	33.0	89.6	26.7*	255	390	460	465	**	**
				150	195	220	265	470	**
				300	480	**	**	**	**
				180	330	410	430	**	**
				135	270	355	375	485	**
			Average	204	333	389	407	491	>500

* Reduction to value indicated caused by conversion of quicklime to hydrated lime.

** Cone index greater than 500. Value of 500 used to determine averages.

Table 3

Summary of Subgrade Conditions before Quicklime Treatment

	Cone Index (along Left and Right Wheel Paths)																	
	Surface		3 in.		6 in.		9 in.		12 in.		15 in.		18 in.		24 in.		30 in.	
Sta	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
0+00	0	0	5	15	5	25	15	30	20	45	30	55	40	50	55	55	70	95
0+05	0	5	5	30	30	30	25	25	30	30	70	35	40	40	60	80	75	60
0+10	3	0	15	15	25	15	20	20	20	30	35	35	35	30	40	45	65	60
0+15	0	5	5	20	10	20	20	22	30	30	45	30	55	40	60	80	70	90
0+20	0	0	5	15	18	20	20	40	22	20	30	30	40	25	65	60	90	70
0+25	0	10	10	20	5	20	15	40	20	45	25	25	30	20	60	40	85	60
0+30	5	5	12	15	15	10	15	15	25	25	35	40	40	35	44	70	65	105
0+35	0	5	25	10	25	15	25	25	35	50	45	45	65	55	80	90	95	105
0+40	0	0	10	10	20	15	20	15	25	25	40	65	45	70	65	70	90	75
0+45	0	10	5	25	15	45	25	20	45	30	50	50	65	55	80	70	90	105
0+50	0	5	10	20	15	25	20	20	20	25	40	30	40	50	65	70	100	95
0+55	10	5	35	20	20	25	20	15	30	20	60	40	70	40	85	60	120	80
0+60	0	5	10	10	25	15	20	30	25	25	20	40	25	65	80	60	110	85
0+65	5	5	30	25	35	30	30	25	30	20	30	35	35	50	100	65	110	95
0+70	30	20	60	55	35	60	35	40	30	25	30	35	25	50	65	95	85	110
0+75	30	10	80	30	45	35	60	45	65	35	55	55	45	50	100	50	300+*	300+*
Avg	5	6	20	21	21	25	23	27	30	30	40	40	43	45	69	66	88	86
All	6		21		23		25		30		40		44		68		87	

	0-6 in.			6-12 in.			12-18 in.			18-24 in.			24-30 in.		
	L	℄	R	L	℄	R	L	℄	R	L	℄	R	L	℄	R
	Water Content, % Dry Soil Wt														
0+20	28.1	27.7	22.5	28.3	29.0	26.5	29.4	31.6	29.0	27.9	29.6	26.1	30.1	28.8	30.0
0+50	29.7	28.3	25.6	27.6	28.5	28.3	27.9	31.4	28.8	26.3	31.1	31.0	28.0	28.3	28.5
Avg	28.9	28.0	24.1	28.0	28.8	27.4	28.7	31.5	28.9	27.1	30.4	28.6	29.1	28.6	29.3
All		27.0			28.1			29.7			28.7			29.0	
	Dry Density, lb/cu ft														
0+20	90.1	90.1	93.7	90.3	90.5	93.8	87.5	86.3	89.6	91.0	89.3	94.0	89.0	88.5	88.6
0+50	89.0	85.3	93.1	89.5	88.9	88.1	90.2	86.1	88.1	91.2	86.2	88.5	87.3	90.6	91.4
Avg	89.6	87.7	93.4	89.9	89.7	91.0	88.9	86.2	88.9	91.1	87.8	91.3	88.2	89.6	90.0
All		90.2			90.2			88.0			90.1			89.3	

Remolding Index

Average (six tests) = 0.98

* Not included in average.

Table 4

Summary of Subgrade Conditions after Quicklime Treatment

Sta	Cone Index (along Left and Right Wheel Paths)																	
	Surface		3 in.		6 in.		9 in.		12 in.		15 in.		18 in.		24 in.		30 in.	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
0+00	60	20	20	20	25	20	25	20	35	30	65	--	95	40	100	100	100	---
0+05	60	80	25	155	20	40	20	60	20	40	30	--	40	30	60	80	100	130
0+10	80	40	70	30	70	30	30	40	25	35	45	--	40	18	60	60	90	100
0+15	35	75	20	120	20	70	20	40	20	20	20	--	30	30	65	60	90	80
0+20	85	40	35	150	20	190	20	70	20	40	30	--	45	30	80	65	110	110
0+25	60	40	35	150	20	180	25	130	40	50	45	--	40	25	90	100	120	155
0+30	120	120	100	160	90	180	30	200	25	110	40	--	40	30	90	60	100	105
0+35	120	120	160	145	120	150	110	300	200	280	160	--	60	35	70	50	105	85
0+40	20	190	110	145	140	150	170	360	20	240	30	--	60	60	60	100	80	110
0+45	45	130	145	150	125	125	40	210	40	245	20	--	20	60	60	55	80	65
0+50	20	220	40	130	100	100	50	240	30	350	60	--	70	30	70	115	95	165
0+55	50	120	110	115	130	110	80	105	35	370	30	--	40	140	60	150	80	150
0+60	130	110	90	170	30	160	20	330	25	270	40	--	85	80	---	60	120	75
0+65	180	140	80	130	80	260	65	300	40	320	30	--	35	30	140	130	140	155
0+70	200	200	250	170	200	195	130	100	40	40	70	--	80	25	135	130	110	175
0+75	300	135	220	275	120	180	90	90	75	95	80	--	140	105	100	170	300+*	300+*
0+00 to 0+25	63	49	34	104	29	88	23	60	27	36	39	--	48	29	76	78	102	115
0+25 to 0+50	65	156	111	146	115	141	80	262	63	245	62	--	50	43	70	76	92	106
0+50 to 0+75	172	141	150	172	112	181	77	185	43	219	50	--	76	76	109	128	113	139

	Water Content, % Dry Solids Wt						Dry Density, lb/cu ft					
	0-8 in.			8-16 in.			0-8 in.			8-16 in.		
	L	℄	R	L	℄	R	L	℄	R	L	℄	R
0+20	26.7	17.6	26.1	27.4	29.3	26.9	79.1	77.0	90.4	89.4	88.2	----
0+50	20.2	20.8	20.4	24.2	28.4	20.5	84.4	77.3	86.2	84.3	88.5	84.0
Avg	23.5	19.2	23.3	25.8	28.9	23.7	81.8	77.2	88.3	86.9	88.4	84.0
All		22.0			26.1			82.4			86.4	

Note: Remolding index test could not be performed owing to aggregated condition of treated soil.
* Not included in average.

Table 5

Cone Index Values Representing Cross Section of Lane at Sta 0+20 and Sta 0+50 before and after Treatment with Quicklime

Depth in.	Cone Index at Distance from Left Edge of Lane											
	At Sta 0+20						At Sta 0+50					
	1 ft	3 ft (Left Track)	6 ft (℄)	9 ft (Right Track)	11 ft	Average	1 ft	3 ft (Left Track)	6 ft (℄)	9 ft (Right Track)	11 ft	Average
						Before Treatment						
Surface	0	0	10	0	0	2	3	0	8	5	12	6
3	10	5	20	15	20	14	5	10	15	20	30	16
6	20	18	15	20	25	20	36	15	15	25	35	25
9	20	20	20	40	40	28	23	20	15	20	47	25
12	30	22	30	20	25	25	30	20	20	25	60	31
15	65	30	45	30	40	42	28	40	23	30	80	40
18	85	40	75	25	60	57	40	40	32	50	90	50
24	100	65	80	60	90	79	65	65	60	70	75	67
30	140	90	100	70	130	106	95	100	75	95	105	94
						After Treatment						
Surface	70	85	70	40	90		85	20	110	220	60	
3	80	35	150	150	150		70	40	50	130	30	
6	65	20	200	190	30		40	100	60	100	20	
9	40	20	135	70	50		35	50	80	240	20	
12	30	20	35	40	60		60	30	100	350	20	
15	45	30	35	---	40		140	60	75	---	30	
18	45	45	40	30	45		90	70	80	30	50	
24	60	80	90	65	120		---	70	85	115	90	
30	95	110	85	110	100		100	95	120	165	120	